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Crumb Rubber as Partial Replacement of Coarse Aggregate in Asphaltic Concrete

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Abstract
This paper presents the evaluation of the effects of crumb rubber on the characteristics of asphaltic concrete with a view to investigating its suitability as partial replacement of coarse aggregates in asphaltic concrete. The waste tyre was obtained from a dump site in Ede and the portion free from steel breeds was cut into smaller pieces and sieved to obtain crumb rubber passing through sieve 12.5mm and retained in 9.5 mm sieve. Asphaltic concrete materials and crumb rubber (CR) were characterized by carrying out particle size distribution, specific gravity, flakiness index, aggregate crushing value, and adsorption tests on the aggregates. Penetration, softening point, and flash point tests were also carried out on bitumen. Asphaltic concrete samples were prepared with partial replacement of coarse aggregate in the asphaltic concrete mix with crumb rubber at 0, 2, 4, 6, 8 and 10% by weight of the total mix. The samples were subjected to Marshall stability test and the values of stability, flow, air void (AV), voids in the mineral aggregate (VMA), and voids filled with bitumen (VFB) were obtained.
The results showed that the penetration, specific gravity and softening point of the bitumen were; 63.02 mm, 1.03 and 49.6 a??, respectively; and the aggregate crushing value, flakiness index, elongation index, water absorption and specific gravity of the granite aggregate were; 23.8 %, 24.1 %, 28.8 %, 0.3 % and 2.74, respectively. The specific gravity of the crumb rubber was 1.10. The result of stability, flow, bulk density, voids filled (VFB), air voids (VA) and voids in mineral aggregate (VMA) of the asphaltic concrete without crumb rubber were; 12.65 kN, 3.41 mm, 2.36 g/cm^3, 79.43 %, 3.94 % and 17.55 % respectively. However, the stability, flow, bulk density, voids filled (VFB), air voids (VA) and voids in mineral aggregate (VMA) of the asphaltic concrete at 2 % optimum crumb rubber were; 11.82 kN, 3.67 mm, 2.35g/cm^3, 76.25 %, 4.63 %, and 18.15 %, respectively.The paper concluded that the properties of compacted asphaltic concrete for wearing course were satisfied at 2 % partial replacement of coarse aggregate with crumb rubber..
Keywords: Crumb rubber, Asphaltic Concrete, Asphaltic Concrete Properties

1. Introduction

Road transportation is an essential part of human activity, and in many ways form the basis of all socio economic and political interactions. Indeed, no two locations will interact effectively without viable means of movement. In many developing countries, inadequate transport facilities are often the norm rather than the exception. Thus, a good transport system is essential to support economic growth and socio-economic development (Duruzoechi, 1999).

Over thc years, road structures have deteriorated more rapidly due to increase in service traffic density, axle loading and low maintenance service. To minimise the damage of pavement surface and increase durability of flexible pavement, the conventional bitumen needs to be improved with regards to performance related properties, such as resistance to permanent deformation (rutting) and fatigue cracking. There are many modification processes and addictive that are currently used in bitumen modifications such as styrene butadiene styrene (SBS), styrene-butadiene rubber (SBR), ethylene vinyl acetate (EVA) and crumb rubber modifier (CRM).

In road pavement construction, the use of crumb rubber in the modification of asphalt is considered as a smart solution for sustainable development by reusing waste materials. Crumb rubber modifier is a rubber from waste tyres which could be truck tyres, car tyres etc. The crumb rubber contains synthetic rubber, natural rubber, total rubber hydrocarbon and acetone extractable, which makes it have high durability, viscosity, high softening point and better resilience (Wanmohd, 2016). Crumb rubber modifier (CRM) can be used in the secondary application as asphalt mixtures either as binder modifier (wet process) or as fine and/or coarse aggregate replacement (dry process). Presently, the large volume of waste tyre resulting from increase in vehicle ownership and traffic volume around the world becomes a serious problem that impact the environment as a result of their volume, non-biodegradability and indiscriminate disposal. Records show that each year between 700,000 and 850,000 scrap tyres are added to the waste stream (Aisien et al., 2002). Recently, Aisien et al. (2006) estimated that about 15 million scrap tyres are now in existence in Nigeria. Therefore, the introduction of scrap tyre rubber into asphalt concrete pavement has the potential to solve this waste problem.

Most importantly, the rubberized asphaltic pavement lasts longer, it is more resilient, less prone to cracking, provides better traction, allows for quieter rides and de-ice more rapidly than conventional pavement (Heitzman, 1992).

2 Materials and Methods

The materials used in this research included bitumen, coarse and fine aggregates, mineral filler and crumb rubber. The bitumen used was 60/70 penetration grade. It was obtained from Espro Asphalt Plant, Ife-Ibadan road, Osun state, Nigeria. The coarse aggregates consisted of granite particles of ranges 19 – 12 mm and 12 – 5 mm, the fine aggregate consisted of granite particles passing 4.75 mm and retained on 75 µm BS sieves, the mineral consisted of granite dust passing 75 µm BS sieve. The aggregates were obtained from Espro quarry, Wasinmi, along Ife-Ibadan road. The waste tyres were obtained from a dump site in Ede, Osun state. The waste tyres were cut into various sizes by mechanical means and the desired size of 9.5 mm was obtained by sieving. The properties of the bitumen, aggregates and the crumb rubber were determined using standard procedures. The mix design proportion consisted of coarse aggregates; 12.5 mm (10 %) and 9.5 mm (30 %), fine aggregate, 4.75 mm (55 %) and mineral filler, 0.075 mm (5 %). The gradation test was carried out according to ASTM C136 (2003).

2.1 Specimen Preparation

The asphaltic concrete samples were prepared in accordance with ASTM D1559 standard at different bitumen contents to obtain the optimum bitumen content (OBC) of 5.9%. This was used as the control mix. Samples were further prepared by replacing the 12 -5 mm size portion with crumb rubber at 2, 4, 6, 8 and 10 % by weight of the total mix.

2.2. Marshal Stability Test

Marshal test was carried out and the values of stability, flow, bulk density, voids filled with bitumen (VFB), air voids (VA), and voids in mineral aggregate (VMA) were determined..

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3. Results and Discussion

3.1 Physical Properties of Bitumen

Table 1 shows the results of the penetration, specific gravity and softening point of bitumen. The values for the penetration, specific gravity and softening point obtained were, 62.2, 1.02 and 50 respectively. The results show the bitumen conforms to all the requirements for asphaltic concrete production (Clause 6371, Table VI-15, FMWH, 19997)

3.2 Physical Properties of Aggregates

Table 2 shows the results of the aggregate and crumb rubber crushing value, flakiness index, elongation index and water absorption. The values for the aggregates are all within allowable limits (Brennan and O'Flaherty, 2002; Kadyali and Lai, 2003; Roberts *et al*., 1996). Furthermore, the aggregate crushing value, flakiness index and water absorption factor of 23.8, 24.1 and 0.38 % respectively, do not exceed the corresponding values of 30, 35 and 0.5 % respectively, provided for in the FMWH, 1997, specification (Clause 6371, Table VI-13). The aggregates are therefore of the quality required

3.3 Aggregate Gradation

Figure 1 shows the aggregate gradation curve. This gradation curve shows that the mix was well graded and the aggregate gradation curve obtained was within the Federal Ministry of Works and Housing (FMWH,1997) specification for wearing coarse.

3.4. Effects of Crumb Rubber on Marshal Properties of Asphaltic Concrete

3.4.1Stability

Figure 2 shows that the stability decreased as the percentage content of the crumb rubber inceased. This follows the normal trend when using the dry process in mixing aggregates and crumb rubber. This decrease in the stability of rubberized asphalt concrete is because crumb rubber is not as hard as the granite aggregate, the rubber tends to absorb some of the energy imparted, resulting in weaker aggregate structure (Hossain et al., 1996).

3.4.2 Flow

As shown in Figure 3 for the flow characteristics of the rubber modified asphaltic concrete, it can be seen that as the crumb rubber content increased, the flow also increased. The increase could be attributed to the fact that rubber has high elastic property which allows it to undergo large deformation from which almost complete, instantaneous recovery is achieved when the load is removed (Beaty,1992).

3.4.3 Air Void

Figure 4 shows the effect of crumb rubber on air void of the mix. It can be seen that there is an increase in the air voids as the percentage replacement increased.. This understandly so as the large size of the rubber particle, could not fill the resulting voids created in the the mix.

3.4.4 Bulk Specific Gravity
Figure 5 shows the effect of crumb rubber on specific gravity. It can be observed the specific gravity of the mix decreased as the percentage rplacement with crumb rubber increased. The resulting decrease in the bulk specific gravity value is due to the lower specific gravity of the Crumb rubber as compared with the aggregates.
3.4.5 Voids Filled with Bitumen
Figure 6 shows the effect of crumb rubber on voids filled with bitumen. It is noticed that as the crumb rubber increased from 0% to 10%, the voids filled with bitumen (VFB) decreased from 79.43% to 60.61%. The reason for the decrease in VFB can be attributed to the increase in air void (VA) of the specimen as the crumb rubber particles being unable to fill the voids created in the mix.
3.4.6 Voids in Mineral Aggregates
Figure 7 shows the effect of crumb rubber on voids in mineral aggregate (VMA). It can be observed that as the crumb rubber content increased from 0% to 10%, there was also an increase in VMA from 17.55% to 21.81%. This increase in the void in the mineral aggregate is attributed to the inability of the crumb rubber to fill the voids of the asphaltic concrete mix.
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4. Conclusion
Based on the results obtained, it can be concluded that the physical properties of bitumen which included penetration, softening point and specific gravity; the physical properties of granite aggregates which included aggregate crushing value, flakiness index, elongation index, water absorption and specific gravity satisfied the specifications for flexible pavement materials. The specific gravity value of 1.10 for crumb rubber indicated that it was a light weight material The modification of the asphaltic concrete mix with different percentages of crumb rubber affected the properties of the asphaltic concrete.

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Table 1: Physical Properties of Grade 60/70 Bitumen

Properties	Test Method	Result
Penetration (0.1mm)	ASTM D-5	63.02
Softening point (a??)	ASTM D-36	ASTM D-36
Specific gravity (g/cm^3)	ASTM D-70	1.03
Flash point (a??)	ASTM D-92	255

Table 2: Physical Properties of Aggregate and Crumb Rubber

Properties	Aggregate	Crumb Rubber
Flakiness index (%)	24.1	19.41
Aggregate crushing value (%)	23.8	0
Water absorption (%)	0.38	1.9
Specific gravity	2.74	1.10

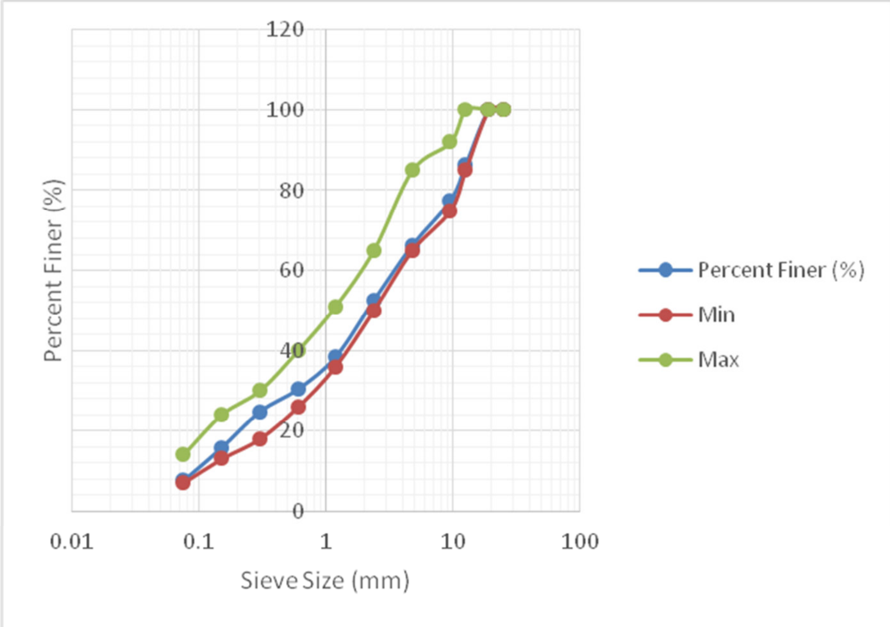

Figure 1: Aggregate Gradation Curve.

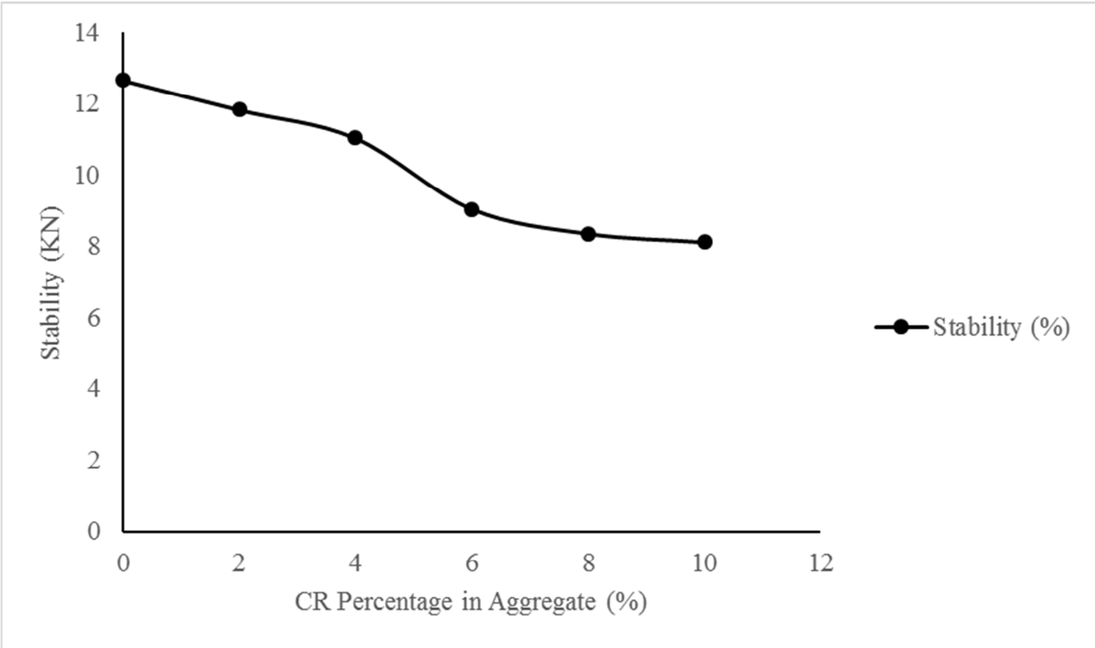

Figure 2:Stability against CR Percentage

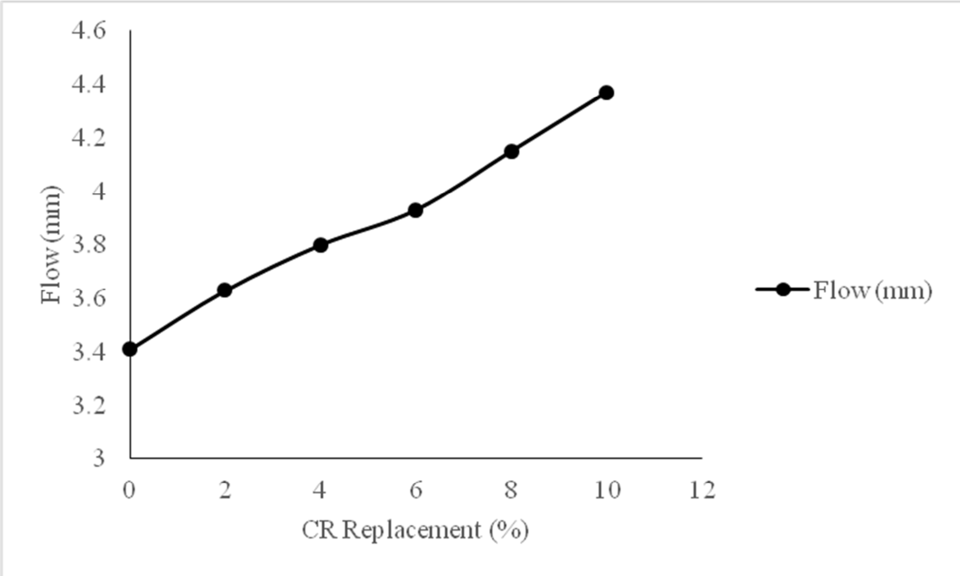

Figure 3:Flow against CR Percentage

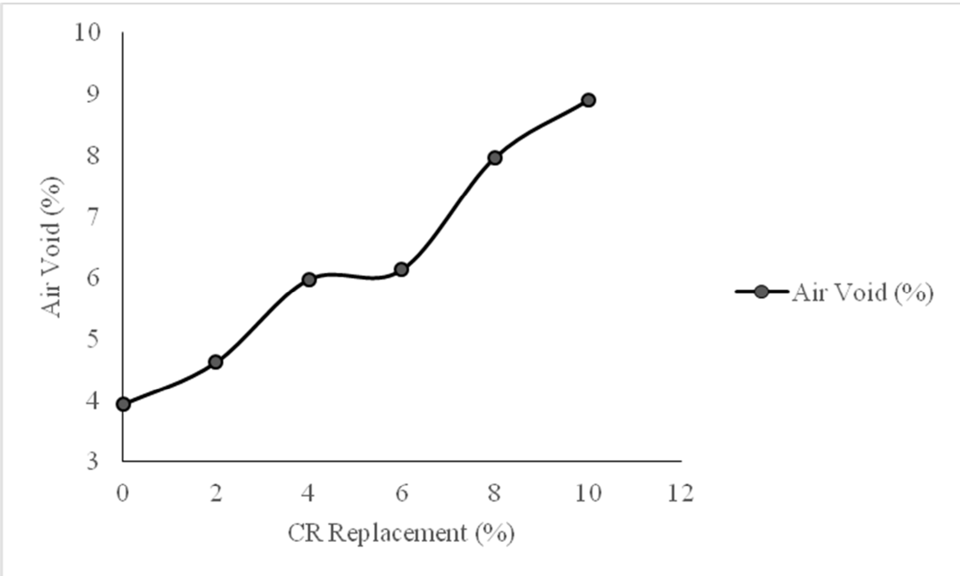

Figure 4:Air Void (VA) against CR Percentage

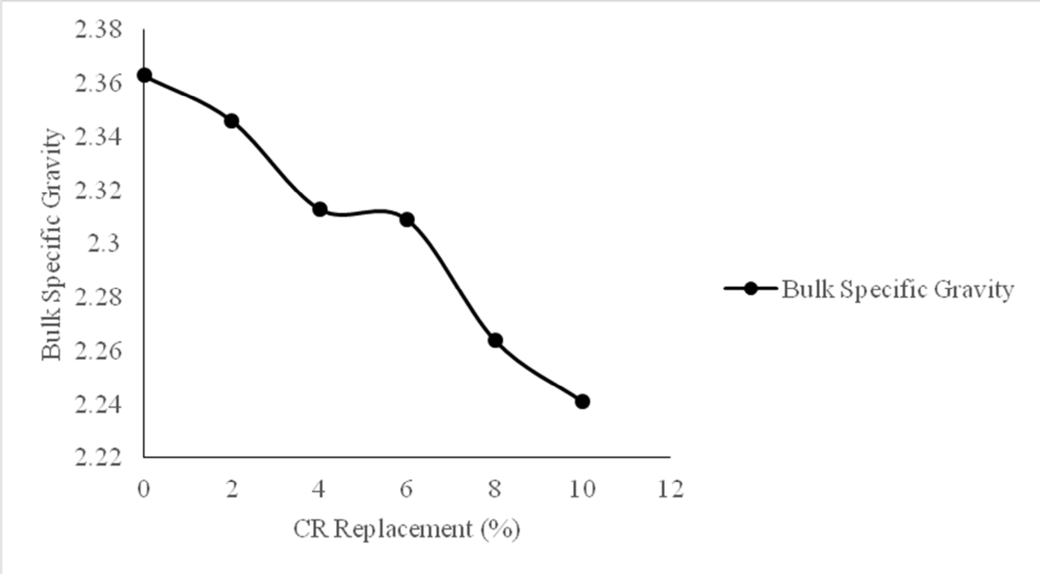

Figure 5:Bulk Specific Gravity (G_{mb}) against CR Percentage

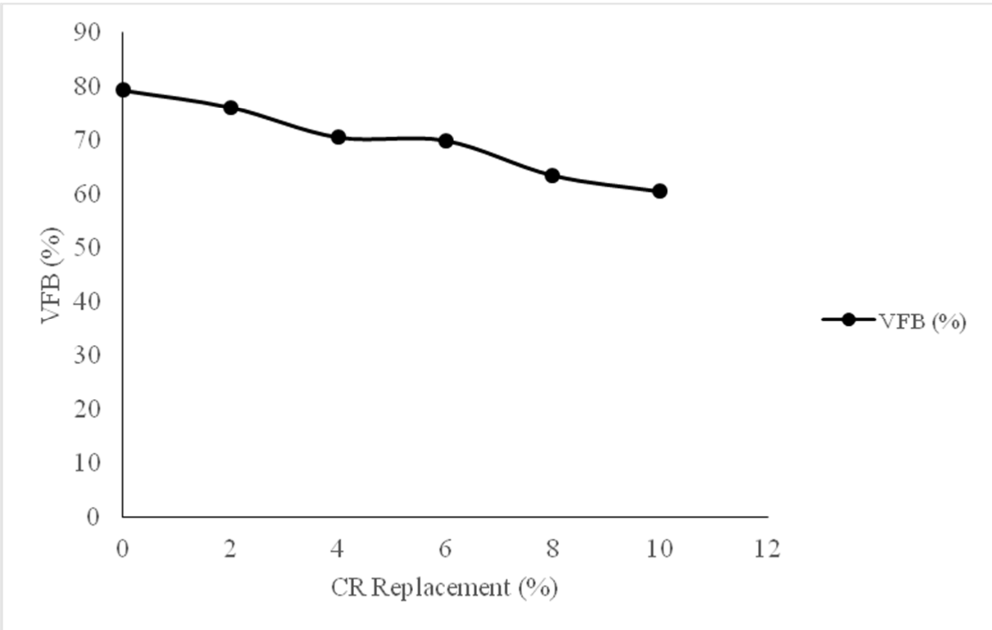

Figure 6:Void Filled with Bitumen (VFB) against CR Percentage.

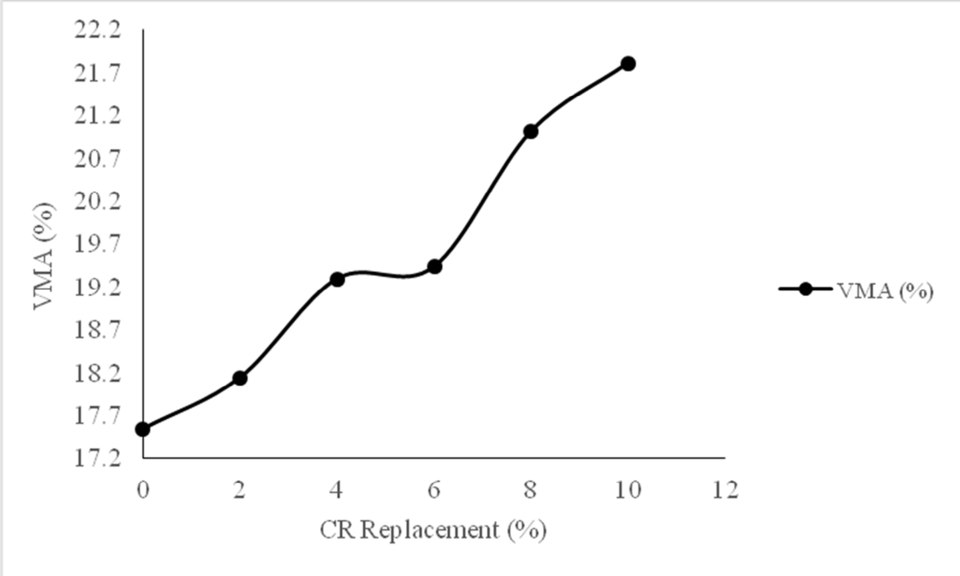

Figure 7:Void in Mineral Aggregate (VMA) against CR Percentage